C-16

化学気相成長法による単層カーボンナノチューブの面内配向制御とカイラリティ制御

Simultaneous control of in-plane Orientation and Chirality of Single-Walled Carbon Nanotubes by Cold-Wall Chemical Vapor Deposition Method

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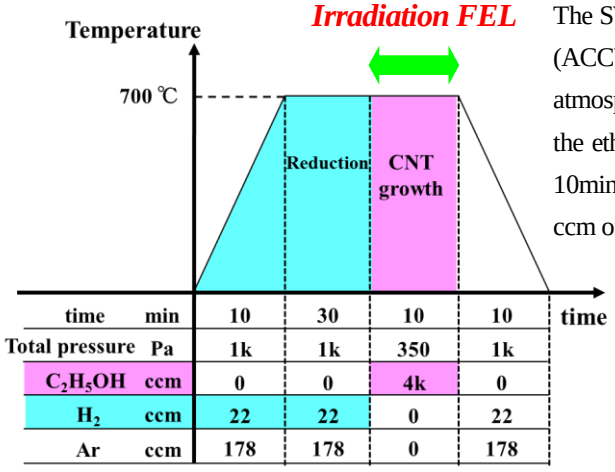
Abstract: The purpose of this study is synthesis of in-plane aligned and chirality controlled single-walled carbon nanotubes (SWNTs) for nano electronic devices. The SWNTs are synthesized on *r*-cut sapphire substrate with free electron laser (FEL) irradiation during growth. On *r*-cut sapphire substrate without FEL, the Raman spectrum indicates growth of mixture of metallic and semiconducting SWNTs. Surface image demonstrates that the aligned SWNTs are observed along the [-111] direction, although the length of the SWNTs is approximately 500 nm with the diameter of 3 ~ 5 nm, which is expected to be bundled. The grown SWNTs with 800nm FEL irradiation is only semiconducting SWNTs on *r*-cut sapphire substrate, though alignment was not observed.

1. Introduction

Single-walled carbon nanotubes (SWNTs) have been regarded as one of the best candidates for future applications in nanoelectronic devices due to its high mobility, high current-carrying capacities, and superb subthreshold characteristics [1]. The drawback for nanoelectronics using SWNTs is that almost all of the current available technologies for the SWNTs growth can only produce a mixture of metallic and semiconducting one. We propose the novel method to grow the SWNTs with specific chirality using free electron laser (FEL) irradiation during growth and in-plane orientation. In our previous report, chirality controlled growth of the single-walled carbon nanotubes had been achieved by irradiating FEL during chemical vapor deposition (CVD) growth [1]. The grown SWNTs are all semiconducting analyzed by a multi excited laser Raman spectra. The possible chirality is (14,0), (13,2), (10,6), and (5,7). The remained issue for applications of the field effect transistor (FET) using just one SWNTs is the in-plane alignment synthesis process.

2. Experimental Procedures

Two ethanol solutions containing cobalt(II) acetate tetrahydrate ($C_4H_6CoO_4 \cdot {}_4H_2O$) and molybdenum(II) acetate dimer ($[(C_2H_3O\text{-})_2Mo]_2$) were prepared as shown in Table Ⅰ. The concentration of catalysts was 0.1wt%. After the surface of the electrodes deposited substrate was treated by ozone, immediately the catalysts particles were formed using a dip coat technique.



time	min	10	30	10	10
Total pressure	Pa	1k	1k	350	1k
C_2H_5OH	ccm	0	0	4k	0
H_2	ccm	22	22	0	22
Ar	ccm	178	178	0	178

The SWNTs growth was carried out by alcohol chemical vapor deposition (ACCVD) method. The substrate was heated up to 700ºC under a reduced atmosphere. The reduction process was done for 30 min, immediately the ethanol gas was introduced for CNTs growth. The growth time was 10min. The heater temperature was gradually decreased at 1 kPa with 200 ccm of Ar and H_2. The 800 nm FEL was irradiated during the growth.

Table Ⅰ Catalyst preparation conditions.

Concentration (wt%)	0. 1
$C_4H_6CoO_4 \cdot 4H_2O$ (mg)	67.6
$[(C_2H_3O_2)_2Mo]_2$ (mg)	35.6
C_2H_5OH (ml)	20

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3. Results and Discussion

Figure 2 shows the Raman spectrum of the SWNTs grown on *r*-cut sapphire substrate. The observed radial breathing mode (RBM) around 160 cm^{-1} indicated the growth of SWNTs with the diameter of 1.1 ~ 1.8 nm. Figure 3 shows the surface image of grown SWNTs on *r*-cut sapphire substrate. The observed needles are expected to be bundled-SWNTs with a diameter of 3 ~ 5 nm. As shown in figures 2, 3 without FEL, the Raman spectra showed growth of mixture metal and semiconducting SWNTs, and the surface image demonstrated the aligned SWNTs along the [-111] direction, although the length of the SWNTs is approximately 500 nm. Figure 4 shows the Raman spectrum of the SWNTs grown on *r*-cut sapphire substrate using the 800nm FEL irradiation. The RBM appeared only in the spectra with 532 nm excitation laser, indicating the growth of SWNTs with the diameter of 1.4 nm. Figure 5 shows the surface image of grown SWNTs on *r*-cut sapphire substrate with 800 nm FEL irradiation. The grown SWNTs with 800nm FEL irradiation is only semiconducting SWNTs on *r*-cut sapphire substrate, though alignment was not observed. The SWNTs is not reason no aligned for FEL irradiation. The aligned CVD condition

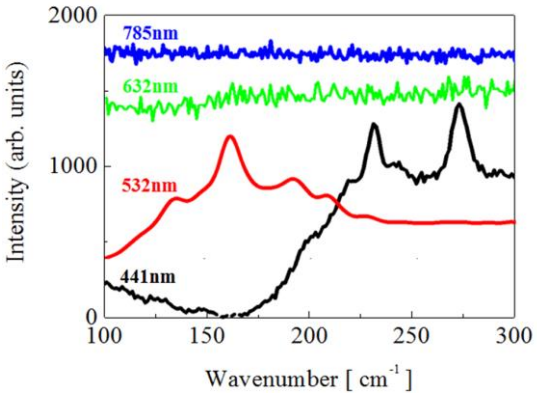

Fig 2. The Raman spectrum of the SWNTs grown on *r*-cut sapphire substrates without FEL

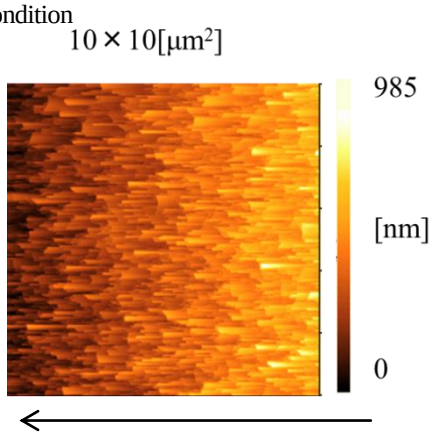

Fig 3. AFM image of SWNTs grown on *r*-cut sapphire substrates without FEL

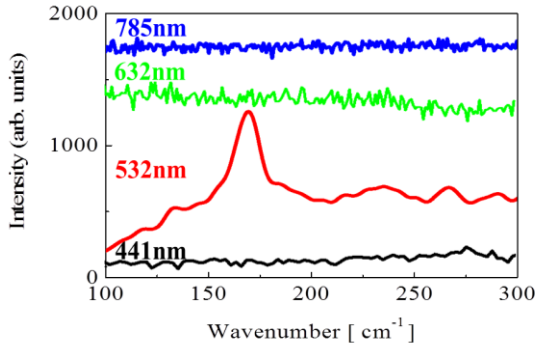

Fig 4. The Raman spectrum of the SWNTs grown on *r*-cut sapphire substrates with 800 nm FEL irradiation..

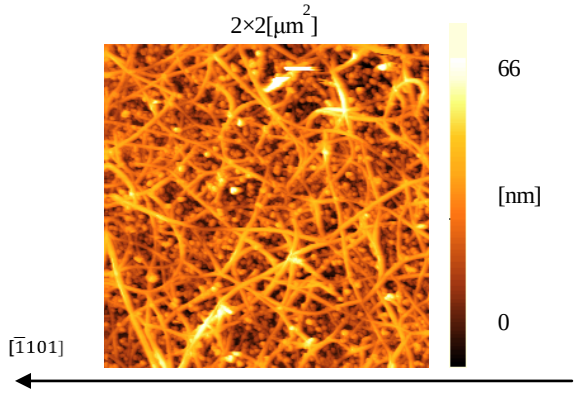

Fig 5. AFM image of SWNTs grown on *r*-cut sapphire substrates with 800 nm FEL irradiation.

4. Summary

The purpose of this study is synthesis of in-plane aligned and chirality controlled single-walled carbon nanotubes (SWNTs) for nano electronic devices. The SWNTs are synthesized on *r*-cut sapphire substrate with free electron laser (FEL) irradiation during growth. On *r*-cut sapphire substrate without FEL, the Raman spectrum indicates growth of mixture of metallic and semiconducting SWNTs. The observed radial breathing mode (RBM) around 160 cm^{-1} mode indicated the growth of SWNTs with the diameter of 1.1 ~ 1.8 nm. Surface image demonstrates that the aligned SWNTs are observed along the [-111] direction, although the length of the SWNTs is approximately 500 nm with the diameter of 3 ~ 5 nm, which is expected to be bundled. The grown SWNTs with 800nm FEL irradiation is only semiconducting SWNTs on *r*-cut sapphire substrate. The RBM appeared only in the spectra with 532 nm excitation laser, indicated the growth of SWNTs with the diameter of 1.4 nm. The surface image of grown SWNTs alignment was not observed

5. References

[1] K. Sakai, S. Doi, N. Iwata, H. Yajima, and H. Yamamoto, IEICE Trans. Electron. **E94-C** (2011) 1861-1866.